

## **CLAIMS**

What is claimed is:

1           1.     A series connected buck-boost regulator comprising:  
2           a control circuit;  
3           a switching circuit for connecting to a source voltage;  
4           an output circuit connected to said switching circuit and for outputting a  
5           load voltage, wherein  
6           said control circuit controls said output circuit and said input circuit for  
7           operating said regulator in a plurality modes including:  
8           a current limiting (CL) mode;  
9           a buck mode; and  
10          a boost mode,  
11          wherein only a fraction of an output power of said regulator is switched  
12          by said switching circuit during one or both of the buck and the  
13          boost modes.

1           2.     The regulator of claim 1 further comprising a transformer having  
2           a primary winding and a center-tapped secondary winding, wherein the center  
3           tap of said secondary winding is for connecting to the source voltage, and  
4           wherein said primary winding is connected to said switching circuit, and  
5           further wherein said secondary winding is connected to said output circuit.

1           3.     The regulator of claim 1, wherein said switching circuit includes  
2           a first switch, a second switch, a third switch, and a fourth switch in a bridge  
3           configuration, and further wherein said output circuit includes a series  
4           connected fifth and sixth switch connected to a series connected seventh and  
5           eighth switch.

1           4.     The regulator of claim 3, wherein, during said boost mode, said  
2           control circuit continuously turns on said fifth switch and said sixth switch, and

3 further wherein said control circuit cycles through a plurality of boost states  
4 including:  
5 a first boost state wherein the first, fourth, and seventh switches are on  
6 and further wherein the second, third, and eighth switches are  
7 off;  
8 a second boost state wherein the seventh and eighth switches are on,  
9 and further wherein the first, second, third, and fourth switches  
10 are off; and  
11 a third boost state wherein the second, third and eighth switches are on  
12 and further wherein the first, fourth, and seventh switches are  
13 off.

1 5. The regulator of claim 3, wherein, during said buck mode, said  
2 control circuit continuously turns on said seventh switch and said eighth  
3 switch, and further wherein said control circuit cycles through a plurality of  
4 buck states including:  
5 a first buck state wherein said first, fourth, and sixth switches are on  
6 and further wherein said second, third, and fifth switches are off;  
7 a second buck state wherein said fifth and sixth switches are on, and  
8 further wherein said first, second, third, and fourth switches are  
9 off; and  
10 a third buck state wherein said second, third, and fifth switches are on,  
11 and further wherein said first, fourth, and sixth switches are off.

1 6. The regulator of claim 3, wherein, during said current limiting  
2 mode, said control circuit continuously turns off said first, second, third, and  
3 fourth switches, and further wherein said control circuit cycles through a  
4 plurality of CL states including:  
5 a first CL state wherein said fifth, sixth, seventh, and eighth switches  
6 are on; and  
7 a second CL state wherein said fifth, sixth, seventh, and eighth  
8 switches are off.

1           7.     The regulator of claim 3, further comprising a ninth switch  
2 connected to said secondary winding which is turned off by said control circuit  
3 during said boost and said buck modes, but is turned on during said  
4 CURRENT LIMITING mode to short out said secondary winding.

1           8.     The regulator of claim 3, wherein each switch has a diode  
2 placed in parallel.

1           9.     The regulator of claim 8, further comprising:  
2 a ninth switch connected to said center tap of said secondary winding  
3 which is turned off by said control circuit during said boost and  
4 said buck modes, but is turned on during said CURRENT  
5 LIMITING mode to short out said secondary winding;  
6 a freewheeling diode connected between said output circuit and a  
7 ground;  
8 a first transformer diode connecting a terminal of said secondary to  
9 said ninth switch;  
10 a second transformer diode connecting another terminal of said  
11 secondary to said ninth switch; and  
12 an inductor for connecting said output circuit to a load.

1           10.    The regulator of claim 9, wherein, during said boost mode, said  
2 control circuit continuously turns on said fifth switch and said sixth switch, and  
3 continuously turns off said ninth switch, and further wherein said control circuit  
4 cycles through a plurality of boost states including:  
5 a first boost state wherein the first, fourth, and seventh switches  
6 are on and further wherein the second, third, and eighth  
7 switches are off;  
8 a second boost state wherein the seventh and eighth switches  
9 are on, and further wherein the first, second, third, and  
10 fourth switches are off; and

11 a third boost state wherein the second, third and eighth switches  
12 are on and further wherein the first, fourth, and seventh  
13 switches are off;  
14 and wherein, during said buck mode, said control circuit continuously  
15 turns on said seventh switch and said eighth switch, and  
16 continuously turns off said ninth switch, and further wherein said  
17 control circuit cycles through a plurality of buck states including:  
18 a first buck state wherein said first, fourth, and sixth switches are  
19 on and further wherein said second, third, and fifth  
20 switches are off;  
21 a second buck state wherein said fifth and sixth switches are on,  
22 and further wherein said first, second, third, and fourth  
23 switches are off; and  
24 a third buck state wherein said second, third, and fifth switches  
25 are on, and further wherein said first, fourth, and sixth  
26 switches are off;  
27 and further wherein, during said CURRENT LIMITING mode, said  
28 control circuit continuously turns off said first, second, third, and  
29 fourth switches, and continuously turns on said ninth switch, and  
30 further wherein said control circuit cycles through a plurality of  
31 CL states including:  
32 a first CL state wherein said fifth, sixth, seventh, and eighth  
33 switches are on; and  
34 a second CL state wherein said fifth, sixth, seventh, and eighth  
35 switches are off.

1 11. The regulator of claim 1, further comprising a transformer having  
2 a primary winding and a center-tapped secondary winding, with the center tap  
3 for connecting to the source voltage, wherein  
4 said switching circuit includes a first switch, a second switch, a third  
5 switch, and a fourth switch in a bridge configuration, said

6                   primary winding of said transformer connected to a center of  
7                   said bridge, and further wherein  
8           said output circuit includes a series connected fifth and sixth switch  
9                   connected to a terminal of said secondary winding and  
10                  connected to a series connected seventh and eighth switch  
11                  connected to another terminal of said secondary winding, and  
12                  also wherein  
13           a ninth switch is included in said regulator for shorting out said  
14                  transformer secondary winding on command from said control  
15                  circuit.

1           12.    The regulator of claim 11, wherein, during said boost mode, said  
2   control circuit continuously turns on said fifth switch and said sixth switch, and  
3   continuously turns off said ninth switch, and further wherein said control circuit  
4   cycles through a plurality of boost states including:  
5                  a first boost state wherein the first, fourth, and seventh switches  
6                          are on and further wherein the second, third, and eighth  
7                          switches are off;  
8                  a second boost state wherein the seventh and eighth switches  
9                          are on, and further wherein the first, second, third, and  
10                         fourth switches are off; and  
11                 a third boost state wherein the second, third and eighth switches  
12                         are on and further wherein the first, fourth, and seventh  
13                         switches are off;  
14           and wherein, during said buck mode, said control circuit continuously  
15                  turns on said seventh switch and said eighth switch, and  
16                  continuously turns off said ninth switch, and further wherein said  
17                  control circuit cycles through a plurality of buck states including:  
18                  a first buck state wherein said first, fourth, and sixth switches are  
19                          on and further wherein said second, third, and fifth  
20                          switches are off;

21 a second buck state wherein said fifth and sixth switches are on,  
22 and further wherein said first, second, third, and fourth  
23 switches are off; and  
24 a third buck state wherein said second, third, and fifth switches  
25 are on, and further wherein said first, fourth, and sixth  
26 switches are off;  
27 and further wherein, during said CURRENT LIMITING mode, said  
28 control circuit continuously turns off said first, second, third, and  
29 fourth switches, and continuously turns on said ninth switch, and  
30 further wherein said control circuit cycles through a plurality of  
31 CL states including:  
32 a first CL state wherein said fifth, sixth, seventh, and eighth  
33 switches are on; and  
34 a second CL state wherein said fifth, sixth, seventh, and eighth  
35 switches are off.

1 13. A series connected buck-boost regulator comprising:  
2 a control circuit;  
3 a transformer having a primary winding and a center-tapped secondary  
4 winding, wherein the center tap of said secondary winding is for  
5 connecting to a source voltage;  
6 a switching circuit controlled by said control circuit and for pulse-width-  
7 modulating the source voltage for inputting into said primary  
8 winding, with said switching circuit including four PWM switches  
9 connected in a bridge configuration with said primary winding  
10 connected to a center of said bridge, wherein each PWM switch  
11 has a diode connected in parallel; and  
12 an output circuit controlled by said control circuit and connected to said  
13 secondary winding for outputting a load voltage, with said output  
14 circuit having two pairs of two series connected output switches  
15 connected in parallel, wherein each output switch also has a  
16 diode connected in parallel.

1           14.    The regulator of claim 13, wherein said control circuit controls a  
2 duty cycle of said pulse-width-modulation of the source voltage and also  
3 drives said output circuit such that said output voltage can be varied in a  
4 range from a minimum voltage less than the source voltage to a maximum  
5 voltage greater than the source voltage.

1           15.    The regulator of claim 14, wherein some substantial fraction of  
2 the power input by the source voltage is not pulse-width-modulated by said  
3 switching circuit during one or more operating modes.

1           16.    The regulator of claim 15, wherein said PWM switches include a  
2 first switch, a second switch, a third switch, and a fourth switch, and further  
3 wherein said output switches include a fifth switch, a sixth switch, a seventh  
4 switch, and an eighth switch,

5           wherein, during said boost mode, said control circuit continuously turns  
6           on said fifth switch and said sixth switch, and further wherein  
7           said control circuit cycles through a plurality of boost states  
8           including:

9           a first boost state wherein the first, fourth, and seventh switches  
10           are on and further wherein the second, third, and eighth  
11           switches are off;

12           a second boost state wherein the seventh and eighth switches  
13           are on, and further wherein the first, second, third, and  
14           fourth switches are off; and

15           a third boost state wherein the second, third and eighth switches  
16           are on and further wherein the first, fourth, and seventh  
17           switches are off;

18           and wherein, during said buck mode, said control circuit continuously  
19           turns on said seventh switch and said eighth switch, and further  
20           wherein said control circuit cycles through a plurality of buck  
21           states including:

22 a first buck state wherein said first, fourth, and sixth switches are  
23 on and further wherein said second, third, and fifth  
24 switches are off;  
25 a second buck state wherein said fifth and sixth switches are on,  
26 and further wherein said first, second, third, and fourth  
27 switches are off; and  
28 a third buck state wherein said second, third, and fifth switches  
29 are on, and further wherein said first, fourth, and sixth  
30 switches are off;  
31 and further wherein, during said current limiting mode, said control  
32 circuit continuously turns off said first, second, third, and fourth  
33 switches, and further wherein said control circuit cycles through  
34 a plurality of CL states including:  
35 a first CL state wherein said fifth, sixth, seventh, and eighth  
36 switches are on; and  
37 a second CL state wherein said fifth, sixth, seventh, and eighth  
38 switches are off.

1 16. The regulator of claim 13, further comprising:  
2 a first transformer diode connected to a terminal of said secondary  
3 winding;  
4 a second transformer diode connected to another terminal of said  
5 secondary winding; and  
6 a transformer shorting switch connected to said center tap of said  
7 secondary and also connected to said first and said second  
8 transformer diodes for shorting said secondary on command  
9 from said control circuit.

1 17. The regulator of claim 16, wherein said PWM switches include a  
2 first switch, a second switch, a third switch, and a fourth switch, and further  
3 wherein said output switches include a fifth switch, a sixth switch, a seventh  
4 switch, and an eighth switch, wherein, during said boost mode,



5        said control circuit continuously turns on said fifth switch and said sixth  
6        switch, and continuously turns off said transformer shorting  
7        switch, and further wherein said control circuit cycles through a  
8        plurality of boost states including:  
9        a first boost state wherein the first, fourth, and seventh switches  
10       are on and further wherein the second, third, and eighth  
11       switches are off;  
12       a second boost state wherein the seventh and eighth switches  
13       are on, and further wherein the first, second, third, and  
14       fourth switches are off; and  
15       a third boost state wherein the second, third and eighth switches  
16       are on and further wherein the first, fourth, and seventh  
17       switches are off;  
18       and wherein, during said buck mode, said control circuit continuously  
19       turns on said seventh switch and said eighth switch, and  
20       continuously turns off said transformer shorting switch, and  
21       further wherein said control circuit cycles through a plurality of  
22       buck states including:  
23       a first buck state wherein said first, fourth, and sixth switches are  
24       on and further wherein said second, third, and fifth  
25       switches are off;  
26       a second buck state wherein said fifth and sixth switches are on,  
27       and further wherein said first, second, third, and fourth  
28       switches are off; and  
29       a third buck state wherein said second, third, and fifth switches  
30       are on, and further wherein said first, fourth, and sixth  
31       switches are off;  
32       and further wherein, during said current limiting mode, said control  
33       circuit continuously turns off said first, second, third, and fourth  
34       switches, and continuously turns on said transformer shorting  
35       switch, and further wherein said control circuit cycles through a  
36       plurality of CL states including:

37                   a first CL state wherein said fifth, sixth, seventh, and eighth  
38                   switches are on; and  
39           a second CL state wherein said fifth, sixth, seventh, and eighth  
40           switches are off.

1           18.    The regulator of claim 17, further comprising:  
2           a freewheeling diode connected between said output circuit and a  
3           ground; and  
4           an inductor for connecting said output circuit to a load.

1           19.    The regulator of claim 18, wherein said control circuit controls a  
2           duty cycle of said pulse-width-modulation of the source voltage and also  
3           drives said output circuit such that said output voltage can be varied in a  
4           range from a minimum voltage less than the source voltage to a maximum  
5           voltage greater than the source voltage.

1           20.    The regulator of claim 19, wherein some substantial fraction of  
2           the power input by the source voltage is not pulse-width-modulated by said  
3           switching circuit during one or more of said modes.